Two-scale transverse structure of the nucleon and central pp collisions at LHC

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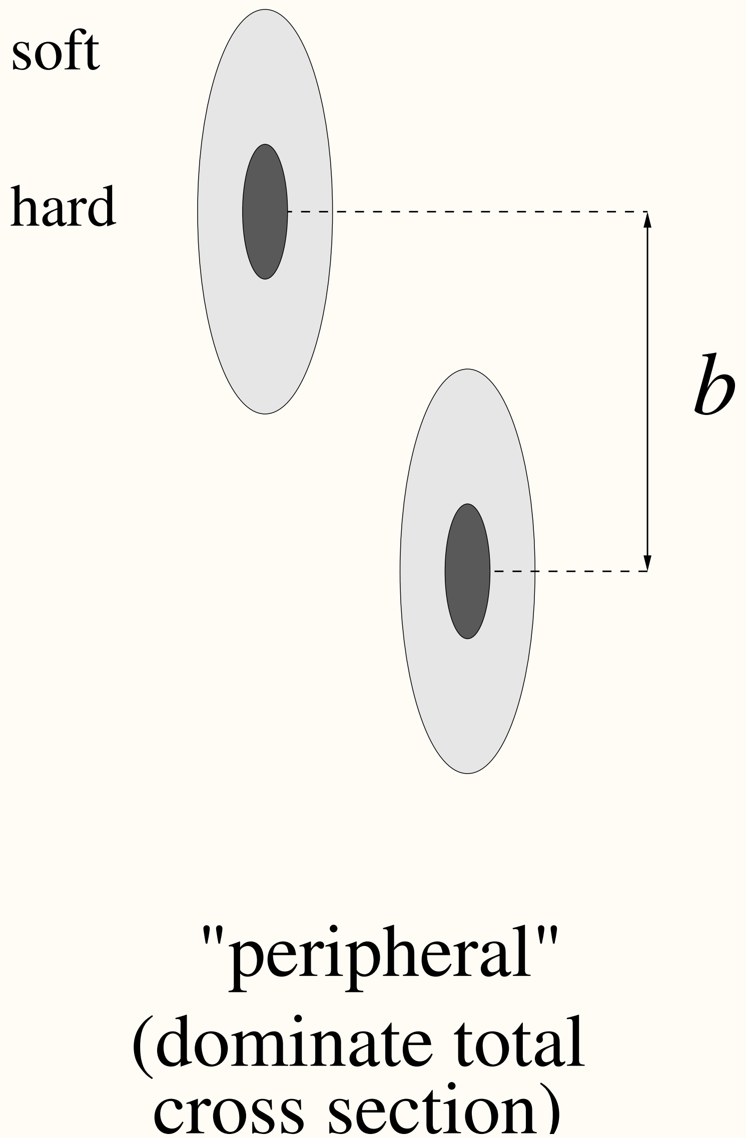
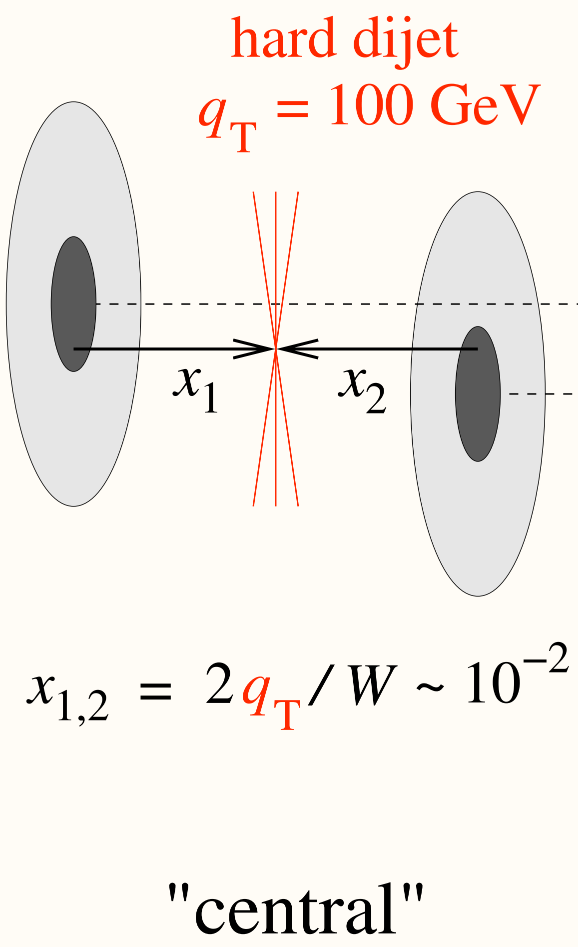
PANIC05

Implication of the two scale picture discussed in C.Weiss talk -- hard processes between partons with moderately large x > 0.01 correspond to collisions where nucleons overlap much stronger



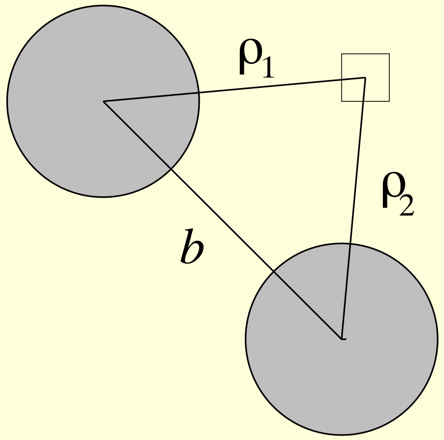


Note that a parton passing through the center of the nucleon encounters gluon density similar to that in the nuclei

Impact parameter distribution for a hard multijet trigger.

For simplicity take $x_1 = x_2$ for colliding partons producing two jets with $x_1 x_2 = 4q_\perp^2/s$. Answer is not sensitive to a significant variation of x_i for fixed $q_\perp$.

The overlap integral of parton distributions in the transverse plane, defining the b–distribution for binary parton collisions producing a dijet follows from the figure:



Hence the distribution of the cross section for events with dijet trigger over the impact parameter b is given by **(F_g, P_2, P_4 depend also on virtuality q)**

$$P_2(b) \equiv \int d^2\rho_1 \int d^2\rho_2 \, \delta^{(2)}(\boldsymbol{b} - \boldsymbol{\rho}_1 + \boldsymbol{\rho}_2) F_g(x_1, \rho_1) \; F_g(x_1, \rho_2),$$

where $x_1 = 2q_\perp/\sqrt{s}$. Obviously $P_2(b)$ is automatically normalized to 1.

For a dipole parameterization: $P_2(b) \;=\; \frac{m_g^2}{12\pi}\left(\frac{m_g b}{2}\right)^3 K_3(m_g b)$

For two binary collisions producing four jets *assuming no correlation between gluons in the transverse plane*:

$$P_4(b) \;=\; \frac{P_2^2(b)}{\int d^2b \; P_2^2(b)}; P_4(b) \;=\; \frac{7\, m_g^2}{36\pi}\left(\frac{m_g b}{2}\right)^6 \left[K_3(m_g b)\right]^2.$$

More realistic estimate for 4 jet case which accounts for parton parton correlations using information from the analysis of the CDF data gives:

$$P_{4,corr}(b) \approx P_2(b) \underbrace{\frac{\sigma_{eff}(model) - \sigma_{eff}(CDF)}{\sigma_{eff}(model)}}_{0.5} + P_4(b) \underbrace{\frac{\sigma_{eff}(CDF)}{\sigma_{eff}(model)}}_{0.5}$$

Impact parameter distribution for minimal bias inelastic interactions interactions can be extracted from the data/ models of elastic scattering using S-channel unitarity relations between elastic, inelastic and total cross sections:

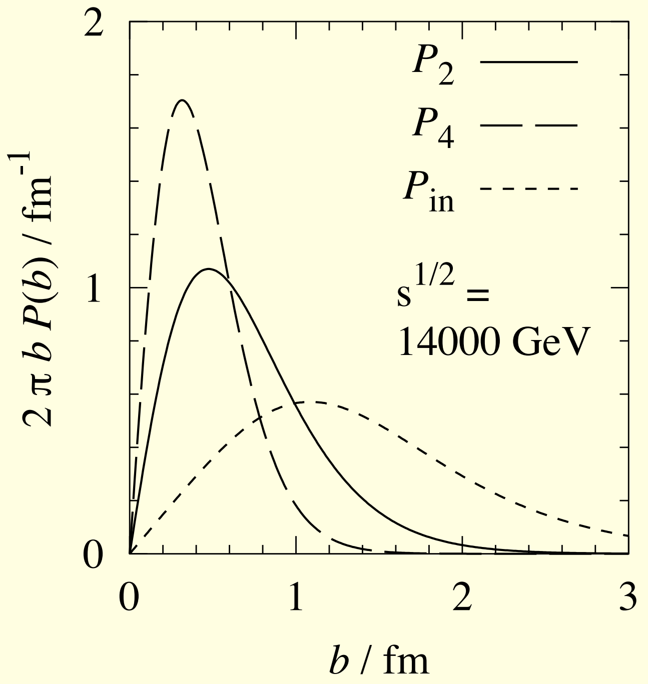
$$\Gamma_h(s,b) = \frac{1}{2is}\frac{1}{(2\pi)^2}\int d^2\vec{q}e^{i\vec{q}\vec{b}}A_{hN}(s,t)$$

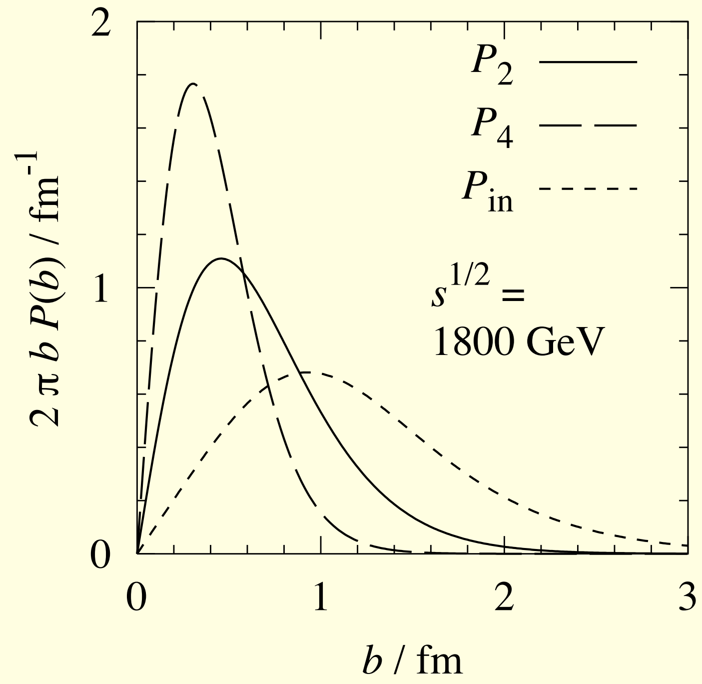
$$ImA(t=0) = s\sigma_{tot}$$

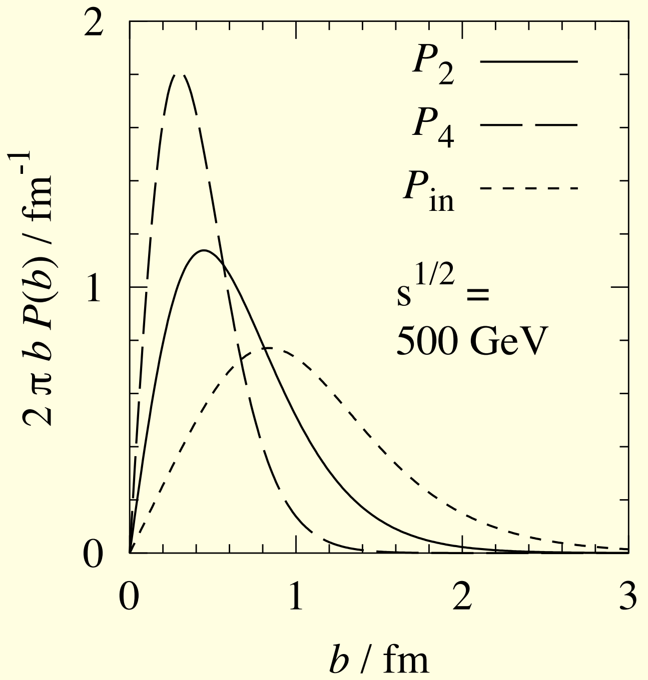
$$\sigma_{tot} = 2\int d^2b\mathrm{Re}\Gamma(s,b)$$

$$\sigma_{el} = \int d^2b|\Gamma(s,b)|^2$$

$$\sigma_{inel} = \int d^2b\underbrace{(1-(1-\mathrm{Re}\Gamma(s,b))^2-[\mathrm{Im}\Gamma(s,b)]^2)}_{\sigma_{inel}(b)}$$







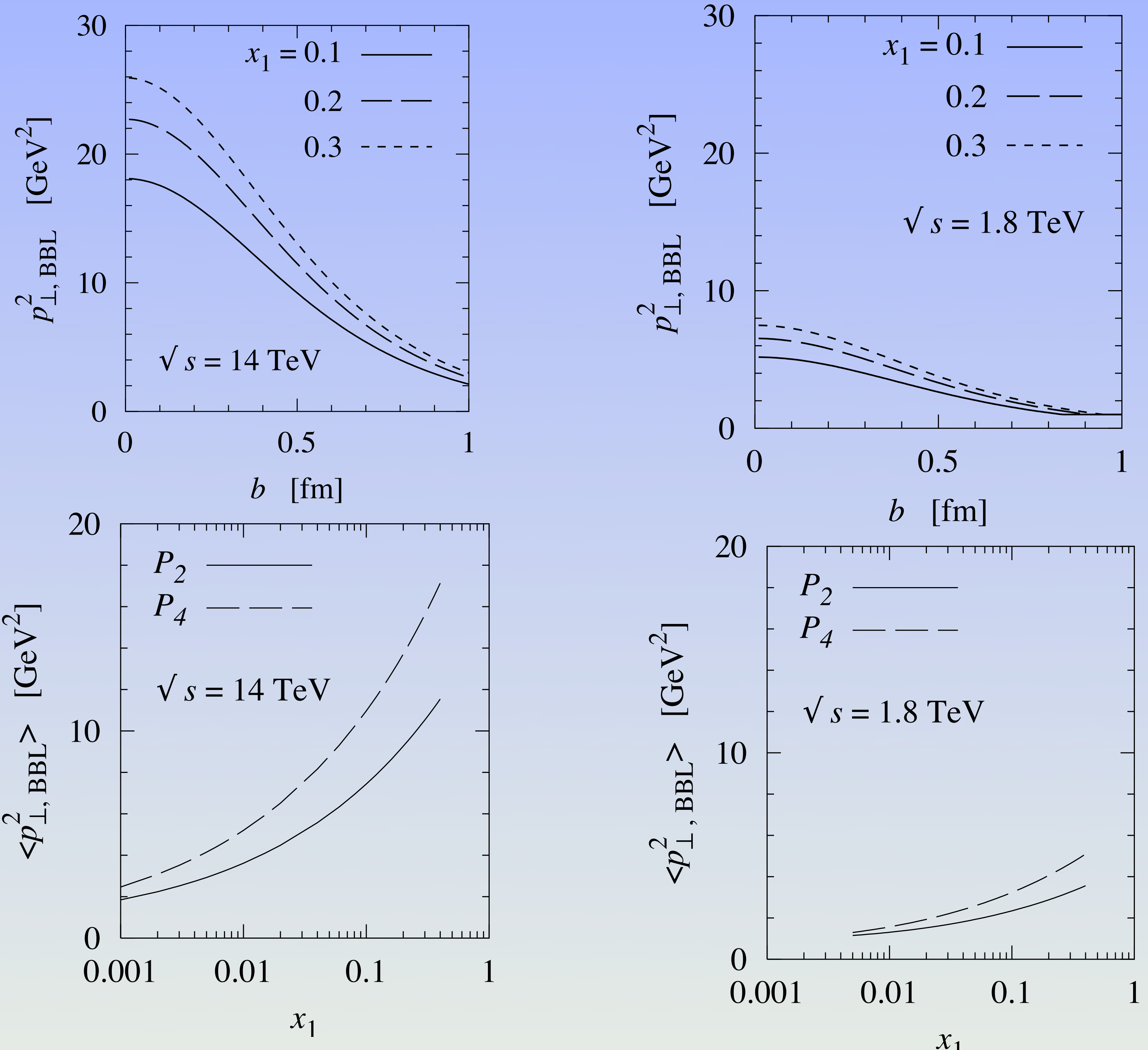
Difference between b-distributions for minimal bias and dijet, four jet events strongly increases with increase of incident energy. *Solid lines:* b–distributions for the dijet trigger, $P_2(b)$, with $q_\perp = 25\, GeV$, as obtained from the dipole–type gluon ρ–profile. *Long–dashed line:* b–distribution for double dijet events, $P_4(b)$. *Short–dashed line*: b–distribution for generic inelastic collisions.

What happens when a parton goes through strong gluon fields? It will be resolved to its constituents if interaction is strong. To estimate the transverse momenta of the resolved system use a second parton as a regularization - consider the propagation of a small dipole of transverse size d - talk of C.Weiss

First we estimate what average transverse momenta are obtained by a parton in the collision at a fixed b and next take into account distribution over b .

- Fixing fast parton's x (x_1) resolved by collision with partons in other proton
- Determining what minimal x are resolved in the second proton for given virtuality $x = \frac{4p_\perp^2}{x_1 s}, Q^2 = 4p_\perp^2$ $small\, x \leftrightarrow large\, x_1$
- for given ρ − distance of the parton from the center of another nucleon − determining maximum virtuality - minimal size of the dipole- d, for which Γ =0.5.
- converting from d to average $\langle p_\perp^2 \rangle \approx (3/2d)^2$

$p_\perp$ acquired by a spectator parton	$\approx$	Maximal $p_\perp$ for which interaction remains black for given x_1

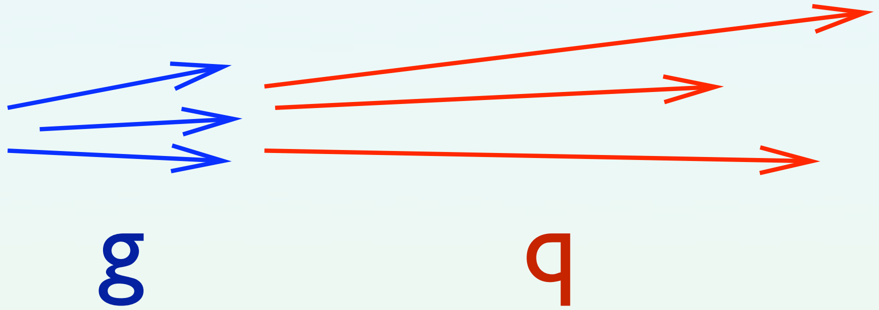


The critical transverse momentum squared, below which the interaction of a leading gluon with the other proton is close to the black disk limit, as a function of b (x_1)

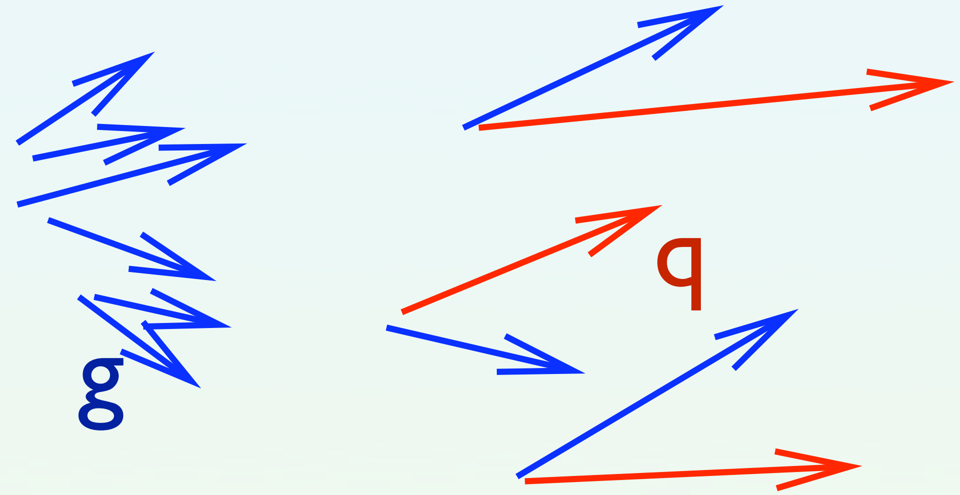
For leading quarks, the values of $p^2_{\perp,BDL}$ are about half of those for gluons.

Also, a spectator parton in the BDL regime loses a finite fraction of its energy *similar to electron energy loss in backscattering of laser off a fast electron beam. Very different from eikonal type picture (multiple elastic scatterings off the classical field)*

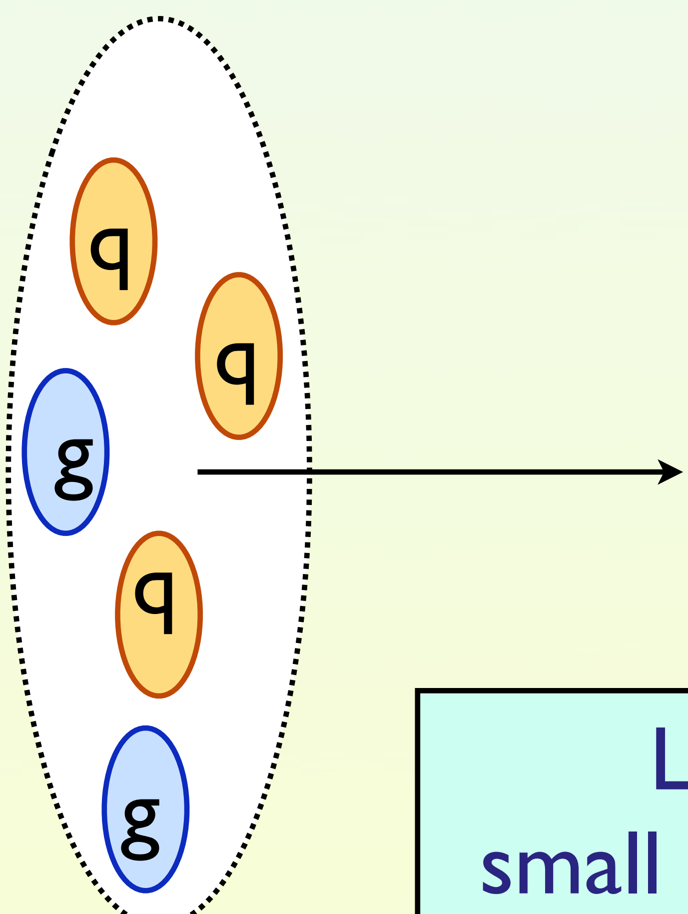
Characteristics of the final state in the central pA(pp) collisions

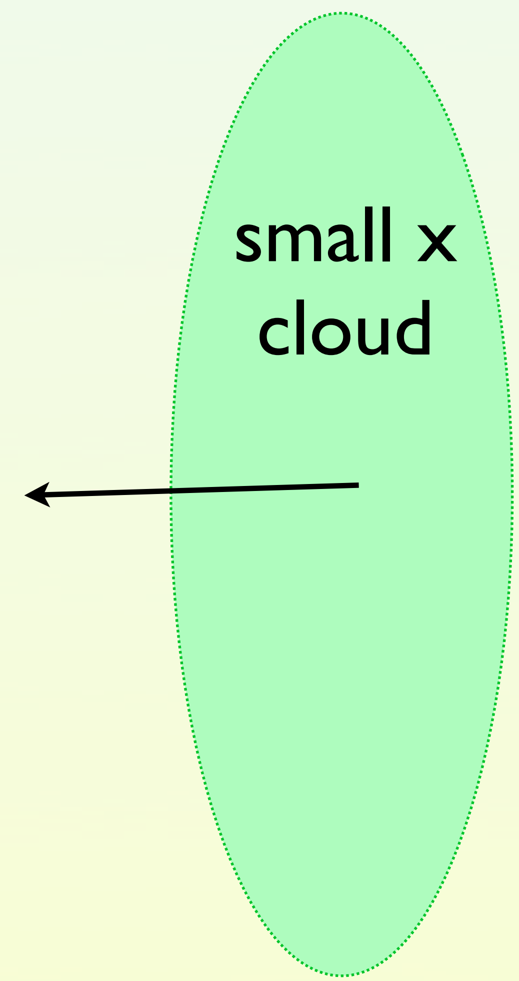


fast partons in a nucleon before collisions



fast partons in a nucleon after central collisions

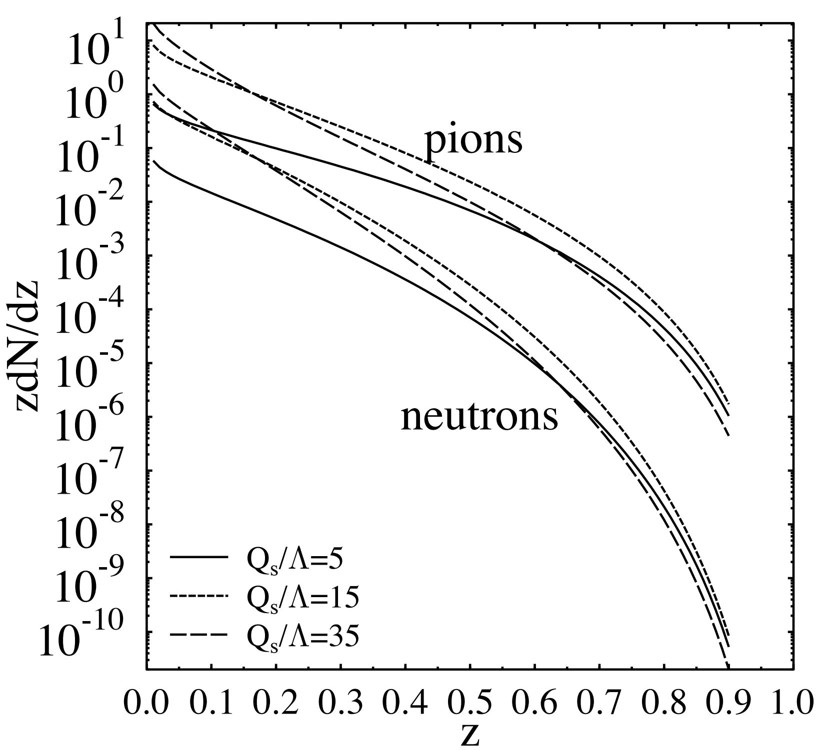


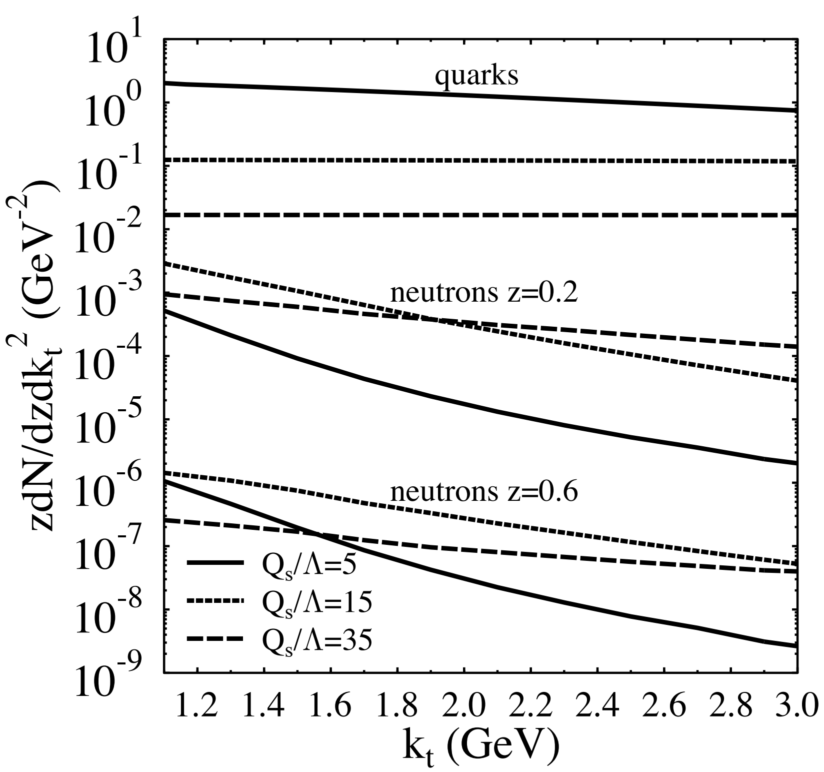


Large x partons burn
small holes in the small x cloud

The leading particle spectrum will be strongly suppressed compared to minimal bias events since each parton fragments independently and splits into a couple of partons with comparable energies. The especially pronounced suppression for nucleons: for $z \geq 0.1$ the differential multiplicity of pions should exceed that of nucleons.

$$\frac{1}{N}\left(\frac{dN}{dz}\right)^{pA\to h+X} = \sum_{a=q,g}\int dx\, x f_a(x, Q^2_{eff}) D_{h/a}(z/x, Q^2_{eff})$$





Longitudinal (integrated over p_t) and transverse

distributions in Color Glass Condensate model for central pA collisions. (Dumitru, Gerland, MS -PRL03). Spectra for central pp - the same trends.

Qualitative predictions for properties of the final states with dijet trigger

- The leading particle spectrum will be strongly suppressed compared to minimal bias events since each parton fragments independently and also looses a fraction of its energy. The especially pronounced suppression for nucleons: for $z \geq 0.1$ the differential multiplicity of pions should exceed that of nucleons.

- A large fraction of the dijet tagged events will have no particles with $z \geq 0.02 - 0.05$
This suppression will occur simultaneously in both fragmentation regions, corresponding to the emergence of long--range rapidity correlations between the fragmentation regions
$\Rightarrow$ large **energy release at rapidities y= 4 - 6 at LHC.**

- Average transverse momenta of the leading particles $\geq 1\ GeV/c$

Many similarities with expectations for spectra of leading hadrons in central pA collisions.

Implications for the searches of new heavy particles at LHC.

☛ Background cannot be modeled based on study of minimal bias events.

☛ Events with production of heavy particles should contain a significant fraction of hadrons with transverse momenta $p_\perp \sim p_{\perp,BDL}$

originating from fragmentation of partons which passed through by the strong gluon field. Transverse momenta of these hadrons are unrelated to the transverse momenta of the jets. Strong increase of multiplicity at central rapidities: a factor ~2 increase observed at FNAL, much larger at LHC.

$\Longrightarrow$ Difficult to identify jets, isolated leptons,... unless $p_\perp(\mathrm{jet}) >> p_{\perp,BDL}$

$\Longrightarrow$ Significant corrections to the LT approximation results for total cross sections and small $p^2_\perp < p^2_{\perp,BDL}$ differential cross sections of new particle production.

What dynamics governs the BDL for hadron-hadron collisions?

Frankfurt, MS , Zhalov 2004

In central pp collision at collider energies leading quarks get transverse momenta > 1 GeV/c

If a leading parton gets a transverse momentum $p_{\perp}$

probability for a nucleon to remain intact is $P_q \sim F_N^2(p_{\perp}^2)$

If $\langle p_{\perp} \rangle > 1 GeV/c \Longrightarrow P_q \ll 1/2$

However there are three leading quarks (and also leading gluons) in each nucleon.

$\Rightarrow$ Probability not to interact $\equiv |1-\Gamma(b)|^2 \leq [P_q]^6 \sim 0$

$$\Gamma(b \sim 0) = 1 \ !!!$$

Explains the collider elastic pp data for small b, predicts an increase of b range, $b<b_F$ where $\Gamma=1$, $b_F=c \ln s$ - Froissart type regime. Actually c slowly grows with energy - so deviations from $\sigma_{tot} \propto \ln^2 s$

Conclusions

★ *Small x physics is an unavoidable component of the new particle physics production at LHC. Significant effects already for Tevatron.*

★ *Minijet activity in events with heavy particles should be much larger than in the minimum bias events or if it is modeled based on soft extrapolation from Tevatron.*

★ *Significant corrects for the LT predictions especially for moderate transverse momenta.*

★ *Many of the discussed effects are not implemented or implemented in a very crude way in the current MC for LHC and cosmic rays*

★ *Forward physics for cosmic rays sensitive to small x physics - connection between pPb at LHC and GZK cosmic rays*

★ *Total opacity at small b ($\Gamma = 1$) is due transition from soft to semi hard QCD - consistent with expected changes of the inelastic events for small impact parameters.*